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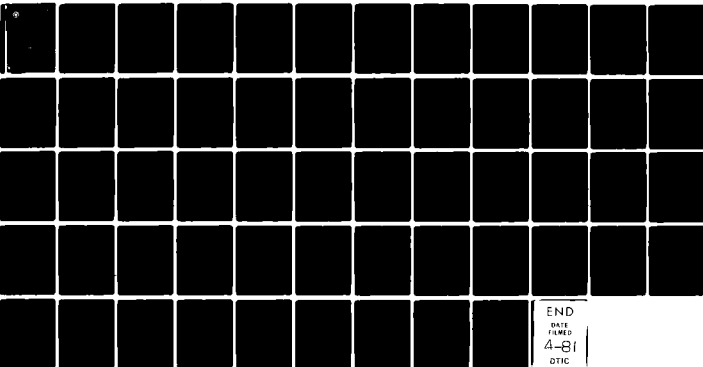
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THE FUTURE OF TESTING: A RESEARCH AGENDA FOR
COGNITIVE PSYCHOLOGY AND PSYCHOMETRICS.

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Robert Glaser

Learning Research and Development Center
University of Pittsburgh

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20. the attainment of increasingly complex levels of skill and understanding. Research on information processing models of aptitude measures and self-monitoring skills is providing an understanding of the abilities for learning tested by intelligence and aptitude tests; understanding of how these abilities are acquired is prerequisite to facilitating their acquisition. These advances in the study of cognition should contribute to redressing social concerns about testing and assessment in education.

ABSTRACT

Current research in cognitive and developmental psychology can influence the development of new psychometric methodology. Research on the diagnosis of performance regularities at different levels of learning and development should contribute to assessment measures that provide information useful for instructional decision and guidance. Investigation of the structure and cognitive processes of highly competent performers in various knowledge domains is beginning to suggest techniques for assessing the attainment of increasingly complex levels of skill and understanding. Research on information processing models of aptitude measures and self-monitoring skills is providing an understanding of the abilities for learning tested by intelligence and aptitude tests; understanding of how these abilities are acquired is prerequisite to facilitating their acquisition. These advances in the study of cognition should contribute to redressing social concerns about testing and assessment in education.

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The Future of Testing: A Research Agenda for
Cognitive Psychology and Psychometrics*

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University of Pittsburgh

It is becoming less than constructive to recount the trials of the psychometric enterprise as it relates to the uses of tests in education. We are all familiar, to some degree, with the thoughtful writing and the rhetoric on such issues as test bias, tests as selective and exclusionary instruments, the questioned value of intelligence tests as assessments of learning potential, the reliability of classification and instructional assignment through tests, and the difficulty of setting appropriate standards for achievement and competence assessment. Pros and cons are expressed with intellectual understanding, ignorance, social justification, and passion by concerned citizens and parents, teacher organizations, psychometricians and psychologists of all kinds, and consumer advocacy groups. The malaise and multilogue continues, and what we must do as best we can is to analyze and understand the deep structure and roots of this unrest.

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Rather than examining, and thereby entering, the debate where all sides can be both praised and faulted in different respects, it seems reasonable to me to reflect on the scene and see what can be learned. I shall do this by taking a futurist's view, and I see this not as avoiding the debate, but hopefully as a way of focusing its directions. Two perspectives seem appropriate. The first is to examine what I see as the social and educational demands of today and tomorrow. The second is to examine relevant research on human cognition and cognitive development in order to speculate on a research agenda for the measurement of human performance that can address these social and educational requirements.

Before beginning this examination, I should say, as a general comment, that I believe that the general uprising of litigation, social questioning, and scientific probing will have lasting benefits. First, test developers and test users, as well as society in general, have been sensitized to how apparently useful practices may actually perpetuate discrimination and inequity. Second, in the face of the growth, acceptance, and power of tests, psychologists and educators have been alerted to the fact that, like other professionals, they will be held responsible for their conduct. They must re-examine their testing practices and their interpretations of tests as professional tools that contribute to educational goals. Third, the attacks on testing have accelerated technical and scientific examination of the fundamental assumptions and basic knowledge that underlie test design and various assessment procedures.

Social and Educational Demands

New developments in testing procedures for the purposes of education will reflect the above trends as researchers and practitioners respond to the critical social-educational demands of our society. I compress these demands into three categories: the need for access to education, the requirement for competence, and the demand for equitable improvement in the skills of learning that contribute to educational attainment.

Access to education. As is well known, the demand for tests arose during the period when school attendance was made compulsory, and when higher education was developing its strengths. Educators faced the unprecedented dilemma of dealing with the range and diversity that individuals bring to schooling. They needed ways of determining which children and youths would be able to profit from some form of instruction as given in ordinary school and college practices and as designed essentially for the majority population. The task of dealing with individual diversity was handled in the context of the social climate of that time, the current forms of school organization, and the emergent psychometric technology. The struggle of educators to deal with diversity was beginning. Selection testing was seen as part of the solution since it could assist in predicting which individuals needed special education or could be discouraged from further schooling.

At the present time, the situation has changed: All children and

youth are in school, albeit with significant instances of exclusionary practices and dropout. It seems clear that we are over the threshold in the transition from education as a highly selective enterprise to one that is focused upon developing an entire population of educated people. A selective system is no longer the prevalent educational demand. (Even though the choice to be selective or not remains.) There is now less emphasis on selecting individuals for available educational opportunities, and more on helping them succeed in these opportunities. The selective emphasis placed too much of the burden for learning on the condition of the student, and too little burden on the possible influences of teaching, training, and instruction. We are now also aware that we have not come close to assessing the limits of effective instruction and that we need to begin to do this. The requirement now is to design a helping society where we devise means for providing educational opportunities for all in equitable ways.

This shift in emphasis poses problems in the use of tests for monitoring access to education. Selection devices used at the university level and tests used to make assignment decisions in earlier education have generally not been designed to guide specific instructional practices. They have rather identified those who are likely to be successful performers (Astin, 1979). As Robert Thorndike says in a 1975 essay entitled "Mr. Binet's Test 70 Years Later":

Accepting the goal of maximizing the effectiveness of education for all children and youth, we must face up to the problem that we have long acknowledged but seldom dealt with

effectively--the problem of providing for each individual the educational treatment that will be most effective in developing that person's potential. A good measure of scholastic aptitude is not automatically a good guide to the optimal educational treatment. Binet's test, like others used in education, must be judged in terms of its ability to facilitate constructive adaptations of educational programs for individuals. This is the challenge for the next 70 years. (p. 7)

J. McVicker Hunt in the same year expressed this condition as follows:

Psychological assessment should guide teaching. It should tell a teacher what kinds of assignment and curricular materials a given child can utilize profitably to foster his psychological development....The form of psychological assessment now most prevalent in education fails utterly to do this. (p. 545)

Thorndike and Hunt are individuals with original ideas but they would agree that their statements have been in our minds for a long time. However, they, like others, realize that such statements must be reiterated often enough until they engender action.

Teachers and schools need information on individuals that is oriented toward instructional decision rather than prediction. Tests in a helping society are not mere indexes that predict that the individual child will adjust to the school, or that relieve the school from assisting the student to achieve as much as possible. The test

and the instructional decision should be an integral event. Separation between a test that monitors access to education and the conditions of that education is only tolerable for those institutions who choose to say this is the way we teach, and our plan is to pick only those applicants who are most successful with our methods.

Test developers and psychometric scholars have, to some extent, put their minds to this problem. But more ingenuity, disregard of past conceptions, and cooperation with and by teachers and schools is required. Reviews of the effectiveness of diagnostic test batteries have been highly critical and are not encouraging (Coles, 1978; Ysseldyke, 1979). It appears that tests continue the tradition of identifying particular symptoms of learning disability or inexperience and then using this information for classification and differential assignment. There is little empirically derived and conceptually understood relationship between test score information and specific instructional activity. Overall, I see little significant progress along these lines unless more flexible environments are introduced in school systems. This would permit differential instructional practices that could be coordinated with useful diagnostic assessment so that the testing and the teaching become integral events.

The requirement for competence. A second aspect of the current social and educational climate is that more people are better educated and literacy levels are higher than ever before. In addition, more people are demanding that they attain these levels. In an historical survey of the nature of literacy, Resnick and Resnick (1977) conclude

the following:

Today, the term "functional literacy" has come to mean the ability to read common texts such as newspapers and manuals and to use the information gained, usually to secure employment. The objectives of functional literacy may seem limited, yet this mass-literacy criterion is stronger than that of any earlier period of history. Achieving universal literacy as it is now defined poses a challenge not previously faced. We estimate that literacy standards in the United States in the 1990's will be both more demanding and more widely applied than any previous standard.

(p. 383)

The point to be made is that we now expect individuals to not only master beginning skills but to also be able to learn from reading and to make inferences and solve problems with verbal and mathematical input. In many subject matter domains, attainment of comprehension and problem solving skills is now a greater problem than mastery of elementary skills.

Related to the demand for higher levels of learning there looms on the horizon the press for education in the skilled trades, the sciences and the professions. Higher levels of competence coupled with productivity and accountability are absolutely required to meet the competition from increasingly prosperous nations of the world. Competition in sports, engineering technology in electronics and steel production, maintaining leads in scientific knowledge and theory, creative writing and other art forms, and devising systems for

education and health care, requires levels of skill and competence that are a singular challenge for our educational system and its related technologies such as testing.

Skills of learning: Intelligence and general aptitude. We are now well aware that the tests of general intelligence and of verbal and quantitative aptitude in use in our educational system measure the kind of intellectual performance called "general scholastic ability." The abilities that are tested are those that correlational evidence has shown to be predictive of success in school learning. These tests are not tests of intelligence in some abstract form. Rather, if we base our conclusions on what these tests measure, in terms of their most effective use--that is, their predictive validity--then the verdict is that they are primarily tests of scholastic aptitude or scholastic ability (e.g., Cronbach, 1970; Scarr, 1978; Tyler, 1963). They measure certain abilities that are helpful in most school work as it is usually conducted in present-day school situations. However, our understanding of these abilities for learning is very incomplete. We need to explain the correlational and factor analytic knowledge that has accumulated in psychometrics in order to be able to enhance or remediate these abilities through educational and other environmental intervention. Many years ago an eminent psychometrician recognized the need for such understanding. In 1964, Quinn McNemar wrote:

There have been thousands of researches on the multitudinous variations from organism to organism....But these studies of individual differences never come to grips with the process,

or operation, by which a given organism achieves an intellectual response. Indeed, it is difficult to see how the available individual difference data can be used even as a starting point for generating a theory as to the process nature of general intelligence or of any other specified ability. (p. 881)

We are now beginning to systematically assess the influences of family, preschool, later schooling, and social-cultural surrounds upon intellectual processes that contribute to intelligence and aptitude. We no longer overlook the fact that test scores are related to acquired abilities, life experiences, and educational opportunity. In contrast to the general attitude in the days of the Army Alpha, and in more recent years, we no longer underemphasize the fact that aptitude tests give weight to educational and social advantage or disadvantage. As one consequence of this, it is now an urgent matter that we attempt to understand the cognitive processes that are involved in tests of mental abilities (Carroll, 1978; Sternberg, 1977), and begin to ask how these abilities might be learned.

I have described three aspects of the current social-educational Zeitgeist: the shift from a selective system to a system that can be helping, adaptive, and instructionally oriented; the necessity for attaining and assessing high levels of competence; and the presence of a social attitude more willing and scientifically able to unpack the factors of mental abilities and to test the limits of their instructability. New thinking and research and development in

testing, as they are intertwined with the goals and methods of education, will need to be responsive to these pressures.

A Research Agenda

It has been necessary for me to talk about social and educational climate, because I believe that education will change in response to these conditions, and coordinate adjustments will be necessary for testing and psychometrics. These adjustments will reflect both social and scientific developments, and it is to the latter that this paper is primarily addressed. In what follows, I review some recent scientific developments that I think will be influencing future theory and practices in instruction and testing. In particular, I discuss: the diagnosis of level of performance, the nature and assessment of competence, and the understanding and improvement of aptitude for learning. The recent work along these lines suggests concepts, techniques, and research possibilities; they comprise a possible research response to the social-educational pressures that I have described.

Diagnosis of Levels of Performance

An important skill of teaching is the ability to synthesize from a student's performance an accurate picture of a student's misconceptions that lead to error. This task goes deeper than identifying incorrect answers and pointing these out to the student: It should identify the nature of the concept or rule that the student is employing that governs his performance in some systematic way (in

most cases, the student's behavior is not random or careless, but is driven by some underlying misconceptions or by incomplete knowledge). Research attempting to analyze performance in this way has been carried out in arithmetic, composition, and the understanding of scientific concepts.

Arithmetic bugs. In work that combines the fields of artificial intelligence and cognitive psychology, Brown and Burton (1978) have developed computer models of procedural skills. They use a technique called "procedural networks" as a framework for constructing diagnostic models--models that capture a student's misconceptions or faulty behavior. Their potentially practical modeling technique provides an identification of mistakes that a student is making and an explanation, in terms of faulty procedures, of why those mistakes are being made. Systems of this kind, computerized or not, have important implications for conceptions of testing because students are evaluated not on the number of errors appearing in their tests, but rather on the basis of the fundamental misconceptions that influence their performance.

Consider the Brown and Burton example in diagnosing arithmetic skills. Here are five items that sample a student's performance doing addition:

41	328	989	66	216
+9	+917	+52	+887	+13
<u>50</u>	<u>1345</u>	<u>1141</u>	<u>1053</u>	<u>229</u>

The task is to discover, by examining these items, the student's bug. Once you have discovered the bug, test your hypothesis by simulating

the student's performance so as to predict his results on subsequent test problems such as the following:

$$\begin{array}{r} 446 \\ +815 \\ \hline \end{array} \qquad \begin{array}{r} 201 \\ +399 \\ \hline \end{array}$$

The bug here is simple: The student, after determining that carrying is necessary, accumulates the amount across columns. For example, in the student's second problem, he proceeds as follows: $8 + 7 = 15$; he writes 5 and carries 1; $2 + 1 = 3$ plus the 1 carry is 4; in the last column, $3 + 9 = 12$ but the 1 carry from the first column is still there, so adding it to this column gives 13, with the answer 1,345. If this is the bug, then the answer to the test problems will be 1,361 and 700. Brown and Burton point out that this bug may not be so absurd if one considers that children might use their fingers to remember the carry and then forget to bend them back after each carry is added. Some other examples from subtraction are shown in Figure 1.

Consider the following case where a student proceeded through a portion of the school year with the teacher thinking that he was exhibiting random behavior in his arithmetic performance. The sample of the student's work is the following:

$$\begin{array}{r} 7 \\ +8 \\ \hline 15 \end{array} \quad \begin{array}{r} 9 \\ +5 \\ \hline 14 \end{array} \quad \begin{array}{r} 8 \\ +3 \\ \hline 11 \end{array} \quad \begin{array}{r} 19 \\ +4 \\ \hline 23 \end{array} \quad \begin{array}{r} 87 \\ +93 \\ \hline 11 \end{array}$$

$$\begin{array}{r} 365 \\ +574 \\ \hline 819 \end{array} \quad \begin{array}{r} 679 \\ +794 \\ \hline 111 \end{array} \quad \begin{array}{r} 27,493 \\ +1,509 \\ \hline 28,991 \end{array}$$

$$\begin{array}{r} 143 \\ - 28 \\ \hline 125 \end{array}$$

The student subtracts the smaller digit in each column from the larger digit regardless of which is on top.

$$\begin{array}{r} 143 \\ - 28 \\ \hline 125 \end{array}$$

When the student needs to borrow, he adds 10 to the top digit of the current column without subtracting 1 from the next column to the left.

$$\begin{array}{r} 1300 \\ - 522 \\ \hline 878 \end{array}$$

When borrowing from a column whose top digit is 0, the student writes 9 but does not continue borrowing from the column to the left of the 0.

$$\begin{array}{r} 140 \\ - 21 \\ \hline 121 \end{array}$$

Whenever the top digit in a column is 0, the student writes the bottom digit in the answer; i.e., $0 - N = N$.

$$\begin{array}{r} 140 \\ - 21 \\ \hline 120 \end{array}$$

Whenever the top digit in a column is 0, the student writes 0 in the answer, i.e., $0 - N = 0$.

$$\begin{array}{r} 1300 \\ - 522 \\ \hline 788 \end{array}$$

When borrowing from a column where the top digit is 0, the student borrows from the next column to the left correctly but writes 10 instead of 9 in this column.

$$\begin{array}{r} 321 \\ - 89 \\ \hline 231 \end{array}$$

When borrowing into a column whose top digit is 1, the student gets 10 instead of 11.

$$\begin{array}{r} 662 \\ - 357 \\ \hline 205 \end{array}$$

Once the student needs to borrow from a column, s/he continues to borrow from every column whether s/he needs to or not.

$$\begin{array}{r} 662 \\ - 357 \\ \hline 115 \end{array}$$

The student always subtracts all borrows from leftmost digit in the top number.

Figure 1. Manifestations of some subtraction bugs (from Brown & Burton 1978).

In this set of items, the clue to the student's faulty procedures is to be seen in the number of ones in his answers. Every time the addition of the column involves a carry, a 1 appears in the column; he is writing down the carry digit and forgetting about the units digit. He is getting the simple additions correct but adopts a different and incorrect procedure when presented with two- and three-place numbers.

The development of such a general diagnostic procedure begins with the decomposition of a complex skill into component procedures that contain the elements of the underlying ability, for example, recognizing a digit, writing a digit, working right to left by one method or left to right by another method, carrying onto the top operand, carrying into the answer, and so forth. A computational procedure employing these components can be developed to perform the skill, and a diagnostic model is then defined as a way of representing a student's procedural knowledge as some variant of the correct version of this procedure. Misconceptions are identified, through the student's patterns of error, that result from incorrect implementations of the various component skills.

Diagnosing performance in this way would be useful for a variety of pedagogical purposes. Brown and Burton (1978) suggest that in addition to its use for diagnostic teaching purposes, it can be used in teacher training. It can encourage the teacher to see that the apparently random, careless, or lazy behavior of a student is frequently a rather complex and logical thought process toward which

teaching can be directed. A diagnostic emphasis of this kind is quite interesting and impressive to teachers; they view it has an important aspect of their own skills and as a way of respecting the systematic intelligence of their students. Such a system of procedural analysis might also be a methodological tool for determining how well a particular test or set of items can discover and delineate common misconceptions that occur in the course of learning.

Writing skill. Somewhat analogous to the identification of systematic misconceptions in arithmetic that I have just described is recent work on the study of error in writing and composition (Bartholomae, 1980; Hayes & Flower, 1980; Shaughnessy, 1977a, 1977b). There has been much discussion, by teachers of basic writing courses, about how the pedagogy of such courses could be improved, and about how systematic inquiry can be undertaken into the nature of the writing skill that students bring to their classes, and how those skills develop into improved writing.

The helping attitude in education that I described earlier is clearly reflected in a leading book in this area--a book by Shaughnessy (1977b) that reflects her experiences in teaching writing during the years when the City University of New York adopted an admissions policy that guaranteed to every city resident with a high school diploma a place in one of its tuition free colleges. Shaughnessy writes:

Those pedagogies that served the profession for years seem no longer appropriate to large numbers of our students, and

their inappropriateness lies largely in the fact that many of our students...are adult beginners and depend as students did not depend in the past upon the classroom and the teacher for the acquisition of the skill of writing.
(p. 317)

This requirement has generated research of an ambitious kind--study of the nature of systematic error and the changes in this performance as writing skill develops. As in the mathematics work, errors are not seen as random guesses, error is seen in a rich, compassionate, and instructive way. Poor performance, which tends to bring feelings of fear and vulnerability to the student and frustration and despair to the teacher, is now seen as a form of systematic intellectual performance that provides a form of information to the student and to the teacher as a basis for development.

In this work, there is little of the neat precision that is possible in the analysis of the arithmetic performance that I described. Yet error analysis in writing can also be a useful method of diagnosing the performance of a writer to discover the rules the writer employs that produce mistakes. Errors fall into three general categories: errors that are evidence of intermediate, transitional rules for writing prose, approximating the standard rules; errors that are slips of the pen as a writer's mind rushes ahead faster than his or her hand; and, errors of dialect interference, where the writer use idioms and syntax from a spoken language.

"The error analyst is primarily concerned...with errors that are evidence of some intermediate system. This kind of error occurs because the writer is an active, competent language user who uses his knowledge that language is rule-governed...to construct hypotheses that can make an irregular or unfamiliar language more manageable. The problem comes when the rule is incorrect or, more properly, when it is idiosyncractic, belonging only to the language of this writer" (Bartholomae, 1980, p. 9). Bartholomae's work on error analysis with remedial entering college students has demonstrated that the errors in the writing performance of these writers evidences not a general lack of linguistic competence, but an idiosyncractic use of language that can be analyzed and categorized to reveal an "interlanguage," the rules the writer uses to record meaning on paper. The myriad errors the inadequate writer makes in producing prose are traced by the error analyst to the rules of this interlanguage or intermediate system that is the writer's approximation to the standard idiom.

To give an example, Bartholomae (1980) examines the errors in one student's two page paper. It is written by a student, John, in response to an assignment to review earlier papers he had written on significant moments in his life, and now his task is to write a paper on the general question of how and why people change:

This assignment call on chosing one of my incident making a last draft out of it. I found this very differcult because I like tham all but you said I had to pick one so the Second incident was decide. Because this one had the most important insight to my life that I indeed learn from. This

insight explain why adulthood mean that much as it dose to me because I think it alway influence me to change and my outlook on certain thing like my point-of-view I have one day and it might change the next week on the same issue. So in these few words I going to write about the incident now. My exprience took place in my high school and the reason was out side of school but I will show you the connection. The sitution took place cause of the type of school I went too. Let me tell you about the sitution first of all what happen was that I got suspense from school. For thing that I fell was out of my control sometime, but it taught me alot about responsability of a growing man. The school suspense me for being late ten time. I had accummate ten dementic and had to bring my mother to school to talk to a conselor and Prinpicable of the school what when on at the meet took me out mentally period.

Bartholomae suggests that in response to this paper an instructor could come to the conclusion that John cannot write and send him off to a workbook to learn how to write correct sentences and then come back to actual writing. A more analytical instructor could chart patterns of error in this text. Of the approximately 40 errors in the first 200 words, the majority fall under fairly specific categories: verb endings, noun plurals, syntax, and spelling. Instruction for the student could be focused on these specific kinds of errors. For example, the verb endings almost all involve "s" or "ed" endings which could indicate dialect interference or a failure to learn tense and

number. Errors of syntax could be divided into punctuation errors, such as not indicating sentence boundaries, or consolidation errors, where the student attempts to construct complex sentences by combining simple ones, but fails to consolidate appropriate elements or ideas.

Further analysis of this paper provides a deeper and probably more instructionally useful analysis of John's writing. Bartholomae has taped students reading their own papers; these tapes reveal the variation between writing on the page and writing that is spoken.

He finds that students often substitute correct forms for the incorrect forms on the pages, even though they are unaware that they make these substitutions. The transcript of John's reading is reproduced below with substitutions and corrections underlined and Bartholomae's comments in parenthesis.

This assignment calls on choosing one of my incident making a last draft out of it. I found this very difficult because I like them all but you said I had to pick one so the Second incident was decided on. Because (John goes back and rereads, connecting up the subordinate clause.) So the second incident was decided on because this one had the most important insight to my life that I indeed learned from. This insight explains why adulthood meant that much as it dose to me because I think it always influences me to change and my outlook on certain things like my point-of-view I have one day and it might change the next week on the same issue. (John goes back and rereads, beginning with "like my

point of view," and he is puzzled but he makes no additional changes.) So in these few words I'm going to write about the incident now. My experience took place because of the type of school I went to (John had written "too.") Let me tell you about the situation (John comes to a full stop.) first of all what happened was that I got suspended from school (no full stop) for things that I felt was out of my control sometime, but it taught me a lot about responsibility of a growing man. The school suspended me for being late ten times. I had accumulated (for "accummate") ten demerits (for "dementic") and had to bring my mother to school to talk to a conselor and the Principal of the school (full stop) what went on at the meeting took me out mentally (full stop) period (with brio).

In this admittedly extreme case, the writer corrects almost every error as he reads the paper even though he is not able to recognize that there are errors or that he has corrected them. For example, when asked to reread sentences and notice any differences, John could not see the error in "frew" or "dementic" or any of the other verb errors, and yet he spoke the correct form of most every verb and corrected every plural. On the basis of such evidence, Bartholomae argues that the problem for students like John appears to be one of performance or knowledge of the procedural rules of writing, not of linguistic competence.

Bartholomae's comparisons of written and spoken text emphasize

the difficulty students can have in editing their writing. Failure to correct a paper is not necessarily evidence of inattention or language disability. Rather failure may result from the student having reached a stage of fluency in writing where he directly accesses a written form of meaningful words (such as "dementic") stored in memory and does not utilize the slower procedure of translating speech into writing.

Research of this kind on error analysis can be of great value for the composition teacher. It provides a perspective on the performance of the learner that is interpretable into teaching practice. Both the teacher and student can see a sensible acceptance of the writer's performance and clear indications of the differences between current performance and a form of language competence acceptable to the teacher and the student. The student's difficulty is understood as a level of procedural skill that requires analysis, understanding, and practice.

With respect to the task of the assessment and diagnosis of student performance, it points out the possibility of assessing a learner's "intermediate system," his current rules for producing the meaning and intent of the writer through the writing code. As we refine our understanding of these performance-based errors, we can better assess the error in written composition that is based upon learned and repairable procedural knowledge and take account of this in instruction.

The work on composition is illustrative of the point I wish to make of the necessary interrelationships between the analytical assessment of performance and effective instruction. At the present time, a number of institutions are using writing tests of some form to classify their students into instructional groups. The intent of research on writing is to analyze performance so that the level at which a student is performing can be specified well enough for effective guidance. Classification of this kind is not seen as an evil form of tracking. Such an interpretation is prevented by the assumption behind the tests: They are a means of identifying the intelligent systematicity of learners that they and the teacher understand can be used for the further improvement of skill.

Rule assessment in knowledge of scientific concepts. Methodology for assessing the underlying rule-structure of performance and the progressive development of performance complexity in children has been carried out by Robert Siegler (Siegler, 1976, 1978). In the course of his experiments on the acquisition of knowledge of scientific concepts, Siegler has formulated an approach to assessing children's knowledge. The "rule assessment approach," as he terms it, is based on two assumptions. First, that human reasoning is rule governed, with the rules progressing from less sophisticated to more sophisticated as a function of age and learning. Second, that a useful way of assessing these rule progressions is to design diagnostic sets of problems that yield distinct performance patterns. This approach, like the arithmetic and writing work that I have described, can determine what rules an individual uses in performing a

task as well as determining what rules are common to various groups of individuals and age groups.

The way the rule assessment procedure works can be illustrated by using a variant of the Inhelder and Piaget (1958) balance scale task that was used in Siegler's early experiments. The balance scale task is applicable over a wide age range; five-year olds may know that balances such as teeter-totters fall to one side when they have more weight on one end; adults however, may often not know the formal rules determining the balance's behavior. The first step in the rule assessment approach is to analyze an understanding of the concept. The balance scale's actions are governed by the physical concept of torque: The scale will dip in the direction of the greater of the two torques acting on the two arms. On a balance beam, pegs are placed at equal intervals from the fulcrum and metal discs of equal weight can be hung on each peg. Torque can be computed by multiplying the number of weights on a peg by the ordinal position of the peg or the distance of the peg from the fulcrum. The side having the greater sum of the products will go down; if the products are equal the arm will balance.

Four rules describe how children perform the balance scale task. Children using Rule I consider only a single dimension--the amount of weight on each side. Children using Rule II proceed using Rule I if the amounts of weight are unequal; but, if the amounts are equal, they also consider the distance of the weight from the fulcrum. A child using Rule III considers both the amount of weight and the

distance, but if one side has more weight and the other has its weight farther from the fulcrum, the child guesses. Finally, Rule IV children compute the torques when necessary and choose the side with the greater value.

Knowledge of the balance scale concept is assessed by presentation of six problem-types (see Figure 2). Three of these problem types can be solved without computing torques. They are: balance problems, with equal amounts of weight equidistant from the fulcrum; weight problems, with different amounts of weight equidistant from the fulcrum; and distance problems, with equal amounts of weights different distances from the fulcrum. The other three types of problems Siegler labels conflict problems, because one side has more weight and the other more distance, thus producing a possible conflict. This combination of rules and problem-types makes it possible to predict the particular errors that children make as well as their percentage of correct answers. For example, on distance problems, children using Rule I should always predict "balance" rather than choosing the side with the weights closer to the fulcrum. On conflict-distance problems, they should choose the side with more weight rather than the one with more distance. Siegler has carried out such assessment for various types of scientific concepts, and uses the information obtained to study developmental progression and to devise instruction that facilitates the acquisition of higher level rules in children whose existing knowledge is at a lower level.

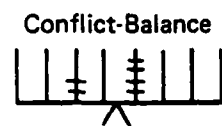
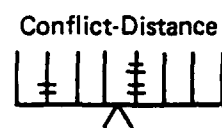
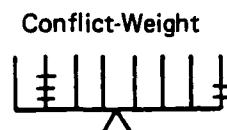
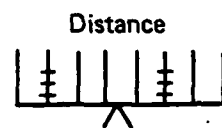
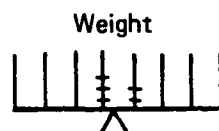
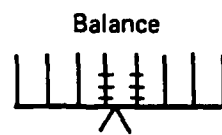


Figure 2. Problem types for balance scale task (from Siegler, 1976).

Rule assessment approaches, such as procedural analysis of arithmetic, error analysis in writing, and performance rules in scientific understanding, suggest possibilities for diagnostic procedures that have the capability of providing a rather deep analysis of the general understanding of a subject matter that an individual brings to test performance. Test items developed in this way could provide an interesting index not only of items correct or incorrect, but a pattern of responding that yields an index of the level of a person's knowledge. There are other interesting psychometric problems in a procedure of this kind. For example, how many items corresponding to a particular problem type need to be presented for a reliable indication of performance? To what extent is there a consistent progression of patterns on different problem types that indicate increasing levels of knowledge from lower to higher order rules? Reliable patterns of response would constitute strong evidence for knowledge advancement as a result of instruction. In assessing creativity, alternative rules generated by an individual that are quite logical, but do not correspond to the specified progression, could be ascertained.

Bringing the concept of diagnosing performance regularities at different levels of learning into the domain of psychometrics continues my theme of an integration between testing theory, teaching practice, and knowledge of human cognition. Rule assessment approaches assume that conceptual development can be thought of as an ordered sequence of learned, partial understandings. Because individuals acquire concepts in subject matter domains to various

levels of understanding and progress through the development of understanding in a reasonably predictable fashion, the assessment of levels of knowledge can be linked to appropriate instructional decisions. This of course is Hunt's problem of the match (1961), and a problem addressed in various attempts to adapt instruction to individual differences (Glaser, 1977; Glaser & Nitko, 1971).

The Nature and Assessment of Competence

Over the past ten to fifteen years, developments in cognitive psychology, artificial intelligence, and language understanding have spurred increasing investigation of the characteristics of high levels of competence. What is it that develops through years of learning and experience that results in expertise in complex skills and in the amazing efficiency, judgment, and competence shown by individuals who are very good at what they do?

In past studies of learning and skill acquisition, too much effort may have been placed on analyzing the prerequisites for learning without sufficient information about the nature of competent performance. Emphasis is now being placed on understanding the cognitive structures of the skilled performer, and analyzing the processes involved in the transformation of a novice into an expert. As we gain increased understanding of the nature of high levels of competence and the kinds of learning and experiences that foster its development, then we should see advances in techniques of instruction and in techniques for assessing the attainment of various levels of

competence.

Understanding expertise. We know little about what it is that the expert acquires that produces his or her high level of performance, and investigation often results in surprising and nonintuitive findings. This work requires detailed and ingenious experimentation because skillful performers appear to observe a set of rules that may not be known as such to the person following them. Before looking at some of the experimental work, an anecdote by a student of writing skill makes this point (Shaughnessy, 1977b). She writes:

In my few attempts to work contrastively with experienced and inexperienced academic writers on the same assignments in order to discover hidden features of competency, I have been surprised by the emergence of certain skills and orientations I had not thought to isolate or emphasize as subjects of instruction. I have noted, for example, that the craft of writing has a larger measure of craftiness in it than our instruction seems to suggest. Experienced academic writers, for example, appear to spend little time deliberating over their main intent in answering a question or developing an essay; this conviction evidently reaches them through some subtle, swift process of assessment and association that has doubtless been highly cultivated after years of writing in academic situations. But after this recognition of intent, there follows a relatively long period of scheming and plotting during which the writer,

often with great cunning, strives to present his or her intent. (p. 319)

Modern seminal work in the study of expertise began with the study of chess skill (Chase & Simon, 1973; de Groot, 1965, 1966; Simon & Chase, 1973), work familiar to all students of cognitive psychology. The striking difference between chess masters and weaker players shows up when they are exposed to an experimental test task--a chess position that is presented for a very brief interval of time, five to ten seconds. In this situation, Masters are able to recall the position almost perfectly from memory and this remarkable ability drops off very rapidly below the Master level. Of particular interest is that this result cannot be attributed to any kind of superior short-term memory capacity of the chess master because when chess pieces are placed randomly on a chess board, recall is equally poor for Masters and weaker players, indicating that chess Masters have the same short-term memory limitations as everyone else.

The series of experiments by Chase and Simon indicate that the chess Master has developed a large repertoire of specific patterns that can be accessed in memory and quickly recognized. It is estimated that the size of the Masters's pattern vocabulary is roughly 50,000 different configurations. In contrast, a good club player seems to have a recognition vocabulary of 1,000 patterns, and a novice has learned to recognize very few patterns. As Chase and Simon point out, given the tens of thousands of hours spent looking at chess positions, this seems comparable to the fact that, with similar levels

of practice, good readers build up comparable recognition vocabularies for words.

Thus, the emphasis in understanding chess expertise is placed on rapid recognition processes that tap acquired knowledge, and high-level competence in this case does not appear to reside in conscious analytical thinking processes. The chess Master is a superior recognizer rather than a deeper thinker. This theoretical view appears to explain several feats of expert chess players. For example,

"it explains how a chess Master is able to defeat dozens of weaker players in simultaneous play: because for the most part he simply relies on his pattern recognition abilities--his so called 'chess intuition'--to generate potentially good moves" (Chase & Chi, 1981).

Findings analogous to those found in the chess work are beginning to be found in subject matter domains taught in formal schooling. In solving problems of the kind taught in elementary physics, investigators have discussed the phenomenon of "physical intuition," much like the chess Master's "chess intuition" (Larkin, McDermott, Simon, & Simon, 1980; Simon & Simon, 1978). Intuition is defined here as the capacity of the knowledgeable physicist to solve difficult problems rapidly, without much conscious deliberation, much like the nonanalytical nature of the chess Master's ability to find good new moves associated with a recognized pattern. In studies of expert-novice differences in physics problem solving carried out with

my colleagues (Chi, Feltovich, & Glaser, in press) we have found that the expert's knowledge is organized around central physics principles whereas the knowledge of the novice is organized around the physical entities or objects directly indicated in the problem description. Both expert and novice solve the problem, but the way the problem is initially represented determines different problem solving procedures that result in differences in efficiency and in ability to handle difficult situations. Similar results are obtained with architects, electronic technicians, and political scientists in the way they recall architectural plans, circuit diagrams and relevant political information (Akin, 1980; Egan & Schwartz, 1979; Voss & Tyler, Note 1). Much of this work is reviewed in a report by Chase and Chi (1981).

In general then, the learning and experience of the competent individual results in knowledge, and in an organization of that knowledge into a fast access pattern¹ recognition or encoding system that greatly reduces the mental processing load; understanding appears to result from these required knowledge patterns that enable an individual to form a particular representation of a problem situation. Novices have systematic knowledge structures at a qualitatively different level than do experts, and the relative adequacy of the initial representation of a situation, that acquired knowledge structures permit, appears to be an index of developing competence.

It is certainly rash to jump to a direct extrapolation from

current experimental tasks to assessment tasks. However, the seeds of possible new procedures are apparent (c.f. Frederiksen, Note 2). As a way of assessing attained competence, will it be possible to devise test tasks that can capture the level of knowledge organization that an individual brings to a problem situation? Since knowledge organization appears to be highly correlated with effective problem solving, assessment might be designed to identify the different forms of knowledge representation that are brought to bear on subject matter situations. As we develop increased understanding of the bases of and growth of competence in various domains of knowledge and skill, we should be able to define the construct validity of tests in terms of the concepts of theories of task performance rather than in terms of less direct correlational evidence.

Basic skills and advanced performance. In certain investigations of high-level competence, it is becoming evident that human ability to perform many attention-demanding tasks is rather limited. It is probably not possible for two attention-demanding tasks to be truly simultaneous (Newell & Simon, 1972; Shiffrin & Schneider, 1977). As in a computer, the simultaneous processing of two tasks can be accomplished by time sharing, by switching attention from one task to another. The influence of this fact on the interaction between basic skills and advanced components of performance has been of interest in investigations of reading comprehension (Lesgold & Perfetti, in press). Attention may alternate between the basic decoding skills of recognizing words and the higher-level skills of comprehension where sentence ideas are integrated into memory.

This oscillation is apparent in the beginning reader who alternately concentrates on sounding out a word and then on considering what the word means in the context of what is being read. While these component processes of reading may work well when tested separately, they may not be efficient enough to work together. Word decoding processes and sentence comprehension processes must be fast enough to avoid desynchronization. Since each mental process takes time, slowness of a component process in interaction with other processes can lead to a breakdown in overall proficiency (Perfetti & Lesgold, 1979). The notion is that low levels of reading performance result from the interfering effects of slow, inefficient word decoding on the execution of higher-level comprehension components. Less-skilled readers are less efficient in elementary word processing tasks; this takes up the time and memory space that is necessary for efficient sentence comprehension, since the latter depends upon the availability of relevant knowledge stored in memory to which the new information can be related.

This general hypothesis of the interference effects between basic and higher-level component processes raises a point for our consideration here. Apparently, word decoding processes need to attain a certain level of efficiency before more advanced processes can be carried out. Hence, to optimize the success of reading instruction, it may be useful to monitor elementary reading practice to ensure that it attains the level of efficiency required for it to minimize interfering effects. The level of efficiency of word decoding that is required is a research question, but assessment of

the efficiency levels reached by readers who eventually become skilled might provide a criterion-referenced performance index of whether an individual has progressed to a point where these processes are efficient enough to facilitate further advancement. In general, empirical and theoretical analyses of this kind might suggest ways of measuring competence in basic skills that contributes to the attainment of advanced levels of achievement (Lesgold & Curtis, in press).

Understanding and Improving Aptitudes for Learning

I turn now to the third item on my agenda for research and development that might contribute to testing in the future--the investigation of measures of aptitude and intelligence that correlate with school achievement. Relevant topics here include: the cognitive analysis of intelligence and aptitude, discrepancy between actually assessed and potential levels of intellectual functioning, and self-regulatory skills that facilitate learning and transfer.

Analysis of measured intelligence and aptitude. In a recent review of the measurement of intellectual abilities, John Carroll (1978) has written the following:

The performances required on many types of mental ability tests--tests of language competence, of ability to manipulate abstract concepts and relationships, of ability to apply knowledge to the solution of problems, and even of the ability to make simple and rapid comparisons of

stimuli...have great and obvious resemblances to performances required in school learning....If these performances are seen as based on learned, developed abilities of a rather generalized character, it would frequently be useful to assess the extent to which an individual had acquired these abilities. This could be for the purpose of determining the extent to which these abilities would need to be improved to prepare the individual for further experiences or learning activities, or of determining what kinds and amounts of intervention might be required to effect such improvements. These determinations, However, would have to be based on more exact information than we now have. (pp. 93-94)

In pursuit of this goal, the past eight years have seen the beginnings of substantial activity on the analysis of intelligence and aptitude test performance in terms of the methodology and concepts of cognitive science. There have been a number of recent reviews and experimental studies on the work being done, and I need not go into detail (Carroll, 1978; Hunt, 1976; Hunt, Frost, & Lunneborg, 1973; Hunt & Lansman, 1975; Pellegrino & Glaser, 1980; Snow, 1980; Sternberg, 1977; Whitely, 1976). In essence, these programs of research attempt to analyze the intellectual functions that are assessed in measures of scholastic aptitude.

In my own work in this area a general and intimidatingly ambitious scheme that has guided our research efforts has evolved from

our own work (Pellegrino & Glaser, 1979) and those of others. It consists of a series of stages of analysis. Our first step has been to identify a domain of tasks associated with an aptitude factor, i.e., a core set of tasks that frequently occur across widely used tests that have demonstrated consistent interrelationships in factor-analytic studies, and that have consistent predictive validity with respect to a criterion performance of academic achievement. The second step is to develop information processing models for the different tasks. These models involve multiple levels of cognitive processing--from estimates of basic memory management processes to higher level strategies controlling the integration and sequencing of the problem solving components required for item solution. The third step is to use the models of task performance as the basis for analyzing item difficulty characteristics and individual and developmental differences in performance.

Following this (and some years down the road), as individual and developmental differences in cognitive processes used on aptitude test tasks are identified, then similar work can proceed on the analysis of criterion tasks used to establish test validities. In this way, the cognitive performances accounting for the correlations of the aptitude measure with criterion performance might be identified. This sets the stage for constructing an information processing theory of validity. Based on such a theory, investigation can proceed on the instructability of the cognitive components of aptitude tasks that facilitate learning of academic criterion tasks.

The "zone of potential development." In Soviet testing philosophy, there has been an interest in the development of reliable methods for the diagnosis of learning disabilities (Brown & French, Note 3; Vygotsky, 1978). In this work, a distinction is made between the child's actual developmental level, i.e., the level of development of a child's mental functioning as might be measured on standardized tests, and the child's level of potential development, i.e., the degree of mental functioning that the child can achieve with some sort of aid and assistance in the course of testing. Both measures are seen as essential for the diagnosis of learning ability and the concomitant design of appropriate instructional or remedial programs. The difference between these measures, or the "zone of potential development," or "proximal development" as Vygotsky termed it, is conceived of as an indication of learning potential. Individuals with the same score on a mental ability test may vary in terms of their cognitive potential. The assumption is that a major difference between average, learning disabled, and more severely retarded children lies in the width of this zone. This is seen as: "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978).

Vygotsky's notions about the relation between assessment of the zone of proximal development and instruction is of interest here. Tests can be used either to determine a level of development whose limits instruction should not exceed, or tests can assess levels of

learning that might possibly be attained. Accomplishing the latter could orient effective instruction toward teaching children what is lacking so far in their development, so that the tested level is interpreted as a possible stepping-stone to a higher level. Thus, learning does not lag behind potential, and effective instruction is defined as that which is in advance of development (Vygotsky, 1978).

Self-regulatory and metacognitive skills. Metacognition is defined in the literature in a number of ways, but I consider here that aspect of it which refers to self-regulatory and self-management skills. This kind of skill has been studied in detail by Brown (1978) and by Belmont and Butterfield (1978) and Meichenbaum (1977). Regulatory skills refer to generalized skills for approaching problems and for monitoring one's performance. These skills are called metacognitive because they are not specific performances or strategies involved in solving a particular problem or carrying out a particular procedure; rather, they refer to the kind of knowledge that enables one to usefully reflect upon and observe one's own performance. As Flavell (1976) has written:

"Metacognition" refers to one's knowledge concerning one's own cognitive processes and products....For example, I am engaging in metacognition...if I notice that I am having more trouble learning A than B; if it strikes me that I should double-check C before accepting it as a fact; if it occurs to me that I had better scrutinize each and every alternative in any multiple-choice type task situation before deciding which is the best one;...if I sense that I

had better make a note of D because I may forget it....Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in...the service of some concrete goal or objective. (p. 232)

These metacognitive abilities are present in mature learners and take on the characteristics of an executive control processor--introduced as an overseer in many current models of memory. In the course of learning and problem solving, representative kinds of regulatory performance include: knowing when or what one knows or does not know; predicting the correctness or outcome of one's performance; planning ahead and efficiently apportioning one's cognitive resources and one's time; and checking and monitoring the outcomes of one's solution or attempt to learn. As Brown (1978) writes: "These forms of executive decision making are perhaps the crux of efficient problem solving because the use of an appropriate piece of knowledge or routine to obtain that knowledge at the right time and in the right place is the essence of intelligence" (p. 82).

Developmental psychologists have indicated that these regulatory skills develop with maturity and that they may be less developed in children with learning disabilities or those who are retarded. It is likely that these skills appear in various forms and levels of competence over a wide range of individuals. The especially interesting characteristic of these skills is that they may be the particular aspect of performance that facilitates transfer from

learning and training situations to new situations. Individuals can be taught a rule or procedure that improves their task performance. But if transfer to new situations is a criterion of general cognitive ability, then it seems important to teach individuals how that skill is to be used and how to monitor its use.

My point in describing self-regulatory activities, on which active research is being pursued at the present time, is to suggest them as important candidates for assessment. Tests of an individual's skill and competence in these self-regulatory skills might be important predictors of success in the kind of problem-solving ability that produces learning.

Summary and Conclusions

I have attempted to juxtapose social-educational requirements with research possibilities that are more and less remote from actual implementation. This juxtaposition might serve a useful purpose because sometimes social requirements shape research questions, and sometimes research findings help frame the attainable form of a social requirement.

I have described three areas of social-educational demand. The first is the shift from a selective educational system to one more designed toward helping individuals succeed in educational opportunities. The research reported indicates new possibilities for diagnostic measures that might provide information helpful for

instructional decision and guidance. The second is the requirement for improved levels of literacy and problem solving ability in various domains of knowledge and skill.

Research on the differences between experts and novices in knowledge structure and cognitive process is beginning to suggest techniques for assessing the attainment of various levels of competence so that increasingly higher standards of skill and understanding might be achieved. The third requirement is the understanding of individual differences in measures of intelligence and aptitude in order to study the extent to which these abilities can be improved to prepare individuals for further learning and experience. Research has begun on the analysis of test performance and test practice in terms of the concepts of information processing and developmental theory, and on the analysis of self-monitoring skills in cognitive performance. This new work is suggesting the kinds of learning skills that might be enhanced through educational and other environmental interventions.

Much of the research that has been described is in early stages, but, seen in terms of the important social-educational demands involved, the importance of these research needs might encourage more resources and talent in these areas.

In 1962 and 1963, (Glaser, 1963; Glaser & Klaus, 1962) I worked on problems of assessing human performance, and out of this grew my concern for making test scores informative about behavior, rather than

about relative performance on poorly specified dimensions. The concept of criterion-referenced measurement was conceived to encourage the development of procedures whereby assessments of proficiency could be referenced to stages along progressions of increasing competence. At that time, a weak link in the construction of proficiency tests was understanding and defining the performance to be measured. The 1962 paper pointed out that systematic techniques needed to be developed to more adequately describe the components of proficiency at various levels of competence. For this purpose, contact was made with certain aspects of the then prevalent theory of learning and instruction, since criterion-referenced measurement is dependent upon an understanding of the components of human performance.

In the ensuing years, outstanding work that has significantly influenced testing concepts, if not teaching, has been carried out by such individuals as Hambleton (1978), Millman (1973), Popham (1978), and many others with some useful comment by Glass (1978) on the issue of standards and criteria. In recent years, there have been significant changes in the theories behind our understanding of competence in areas of complex knowledge and skills. And in large part, I have attempted here to look at our new understanding and relate it to possible developments in testing and psychometrics.

The thesis of Anastasi's presidential address to this division in 1966 (reminiscent of Cronbach's address in 1957) was that psychological testing should be brought into closer contact with other areas of psychology (Anastasi, 1967). Increasing specialization, she

said, "has led to a concentration upon techniques for test construction without sufficient consideration of psychological research for the interpretation of test scores" (p. 305). In 1977, Green in his presidential address concluded that it would do no good to use tests as scapegoats for problems that demand social action (Green, 1978). In this paper, I have tried to combine the wisdom of these individuals by presenting areas of social concern where education and testing might profit from coordination with potentially helpful areas of psychological research.

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